Marrying information and spacetime through correlation diagrams

arXiv: 1909.05322v2 (world quantum gravity)

arXiv:2001.03142 (correlational quantum theory)

And manuscript in preparation

Ding Jia (贾丁)
Perimeter Institute
University of Waterloo

QISS 2020

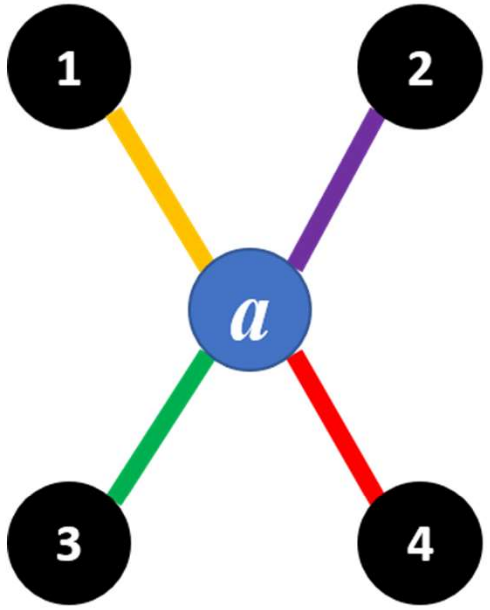
January 17, 2020

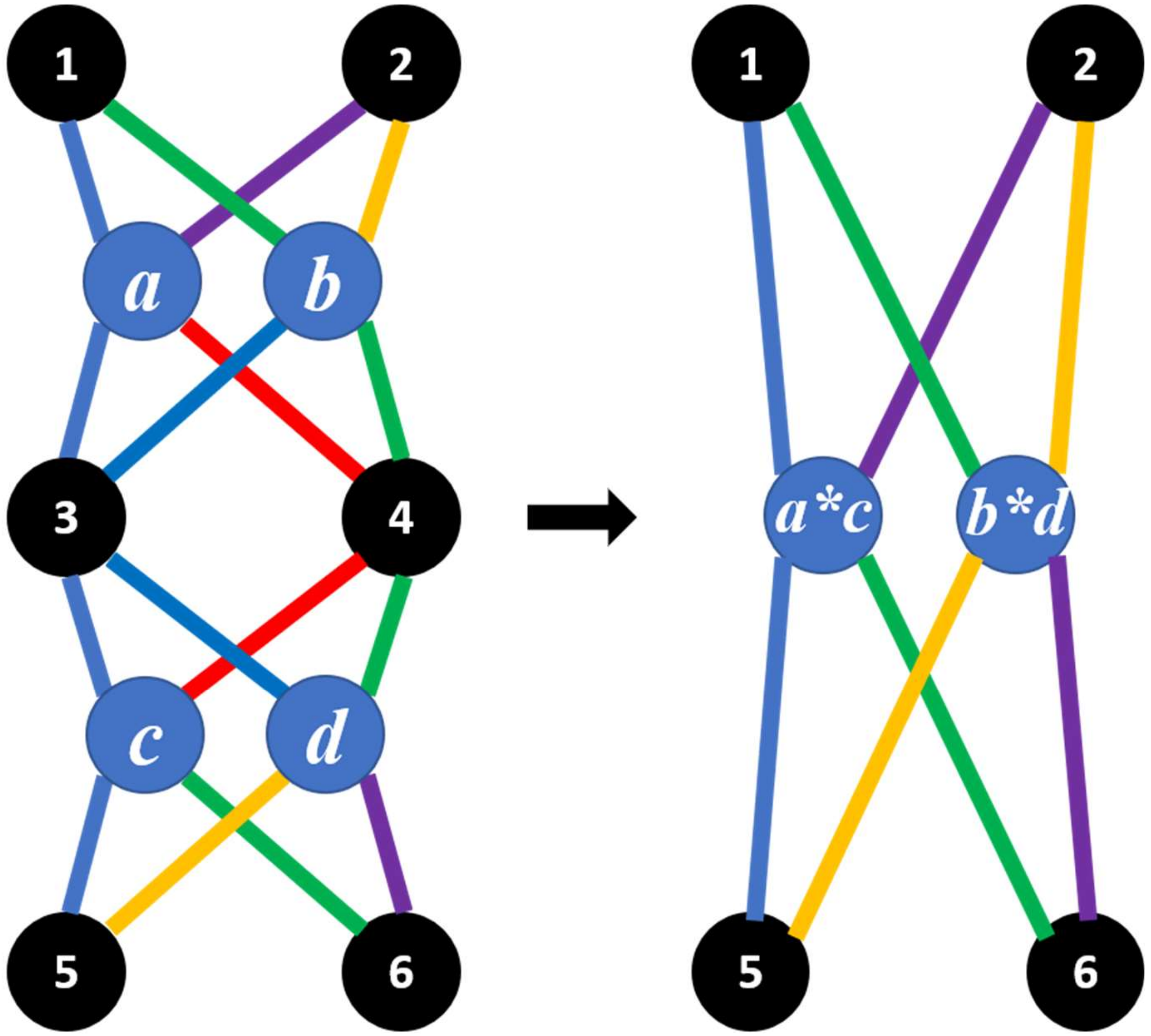
Hong Kong, China

Outline

- Correlation diagram formulation of quantum information
  -Application: characterization of processes with correlation constraint
- Correlation diagram formulation of quantum field theory
  -Feynman diagrams as topological classes of correlation configurations
- World Quantum Gravity
  -Non-perturbative, Lorentzian, path integral approach
  -Idea: relational variable $g_{ab}(x) \to \sigma(x,y)$
  -UV regular for both gravity and matter (seems)
  -Spacetime singularity-free (seems)
  -Efficiently computable: Real and positive (up to convention) amplitude after Hardy sum, suitable for Monte Carlo (seems)
  -Indefinite causal structure through Hardy sum crucial for all three features!

Correlation diagrams





- Color: correlation type
- Letter: correlation strength

Quantum information with correlation diagrams

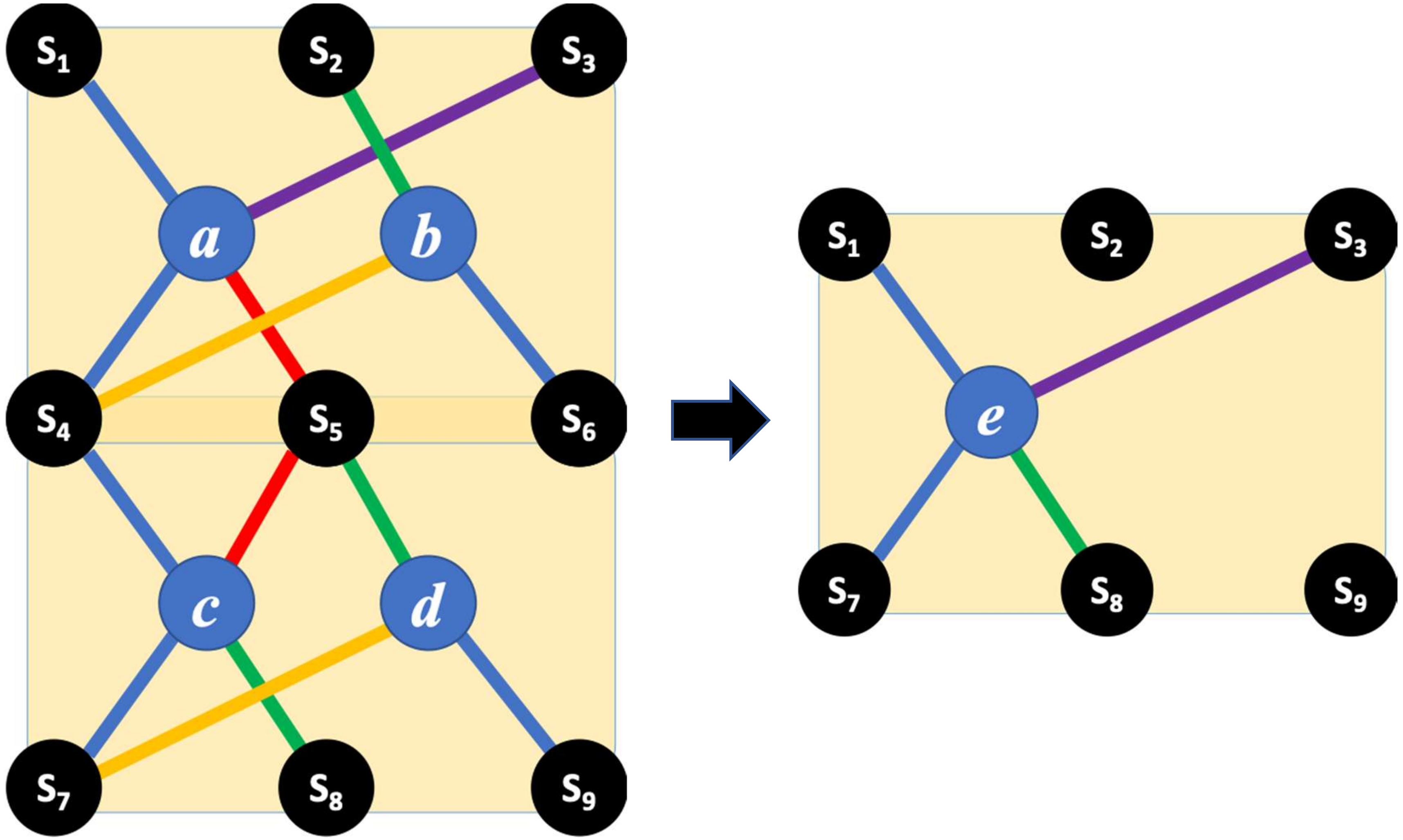
- Pauli operator expansion (Oreshkov, Costa, Brukner; …)

$$A=\sum_{i,j,\dots,k} \boxed{a_{ij\dots k}}\, \sigma_i^{s_1} \otimes \sigma_j^{s_2} \dots \otimes \sigma_k^{s_n}$$

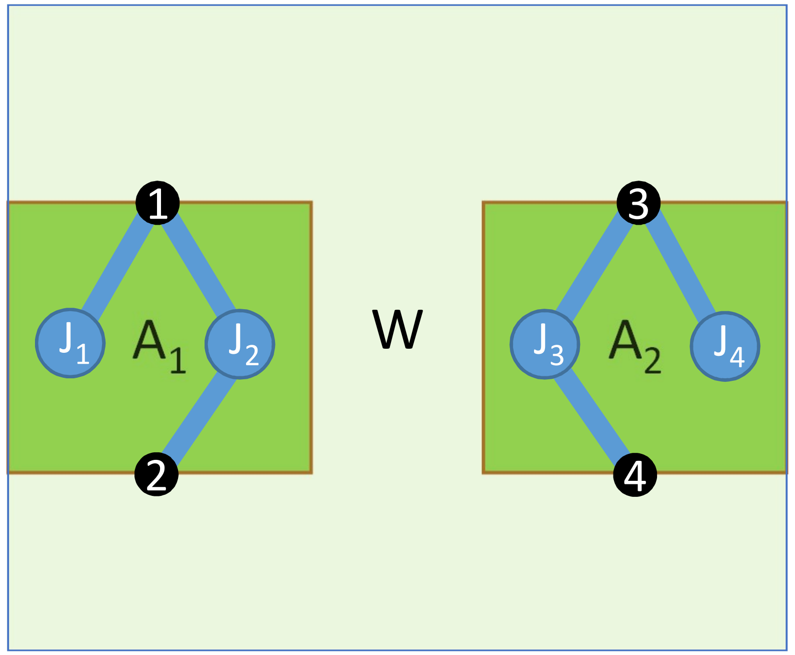
Choi

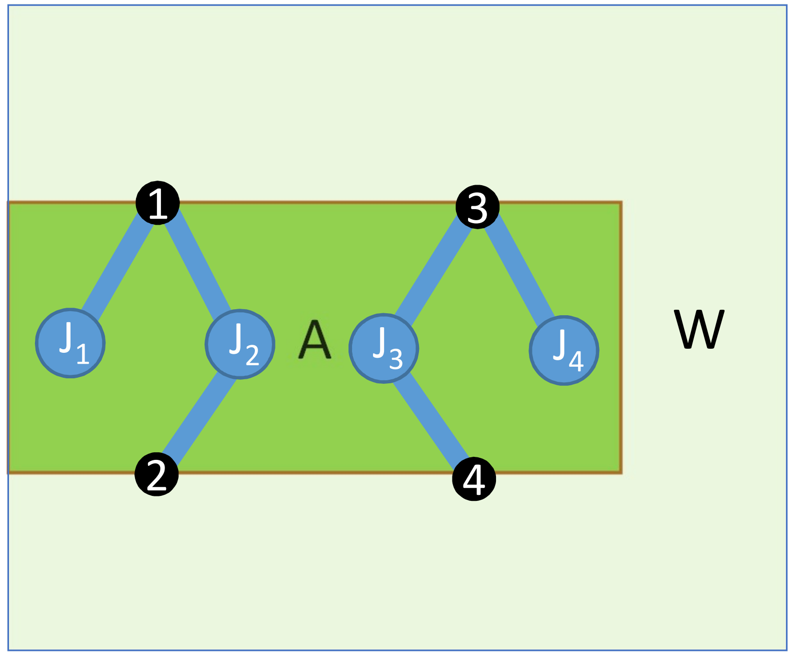
coefficients

types



More general processes

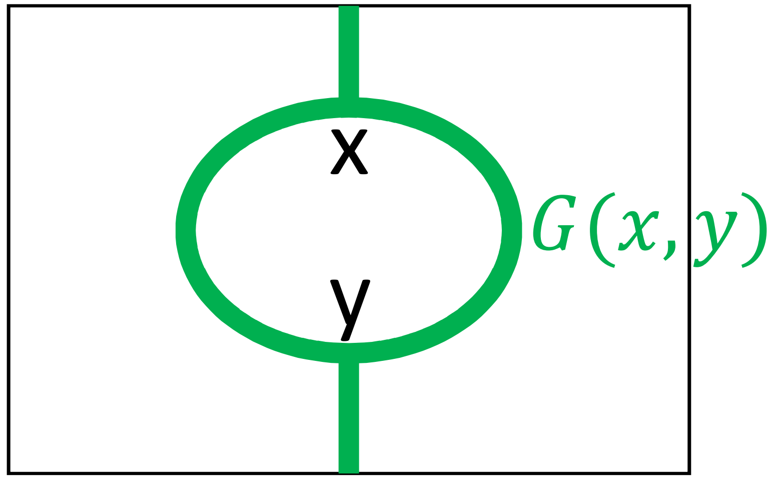


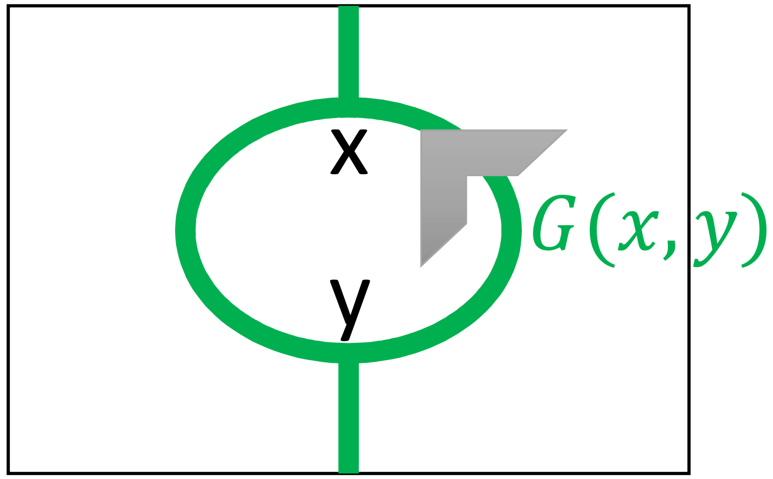


- Binary string calculus characterizing processes with correlation constraint
  arXiv:2001.03142

(Works for both time-symmetric and time-asymmetric cases!)

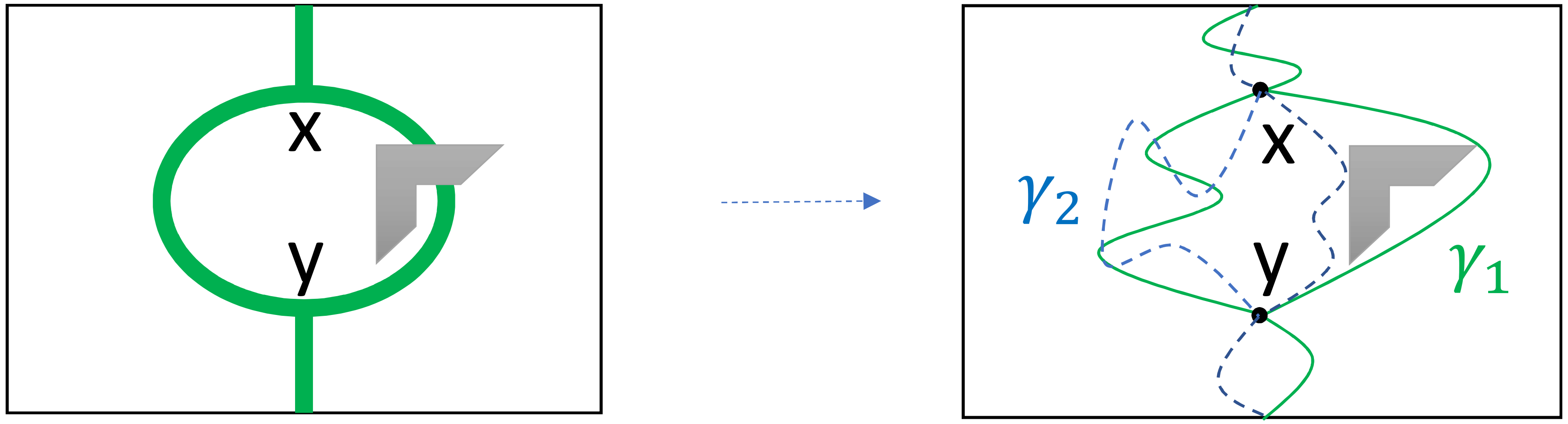
Question: QFT with walls?





- Does the spacetime wall affect the theory?

"Worldline formalism"



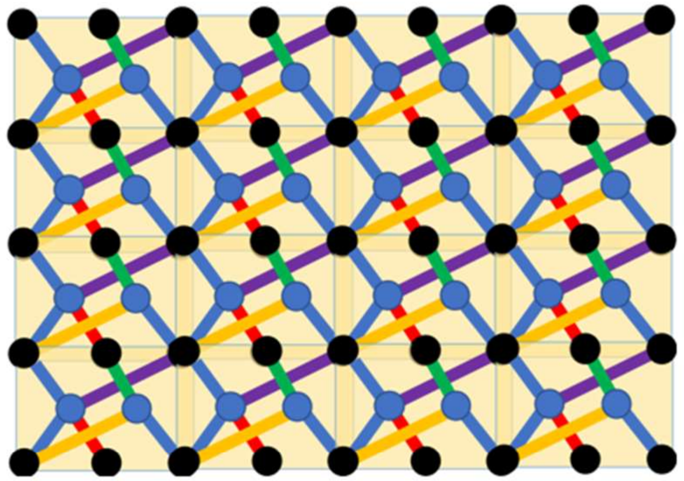
γ correlation diagrams

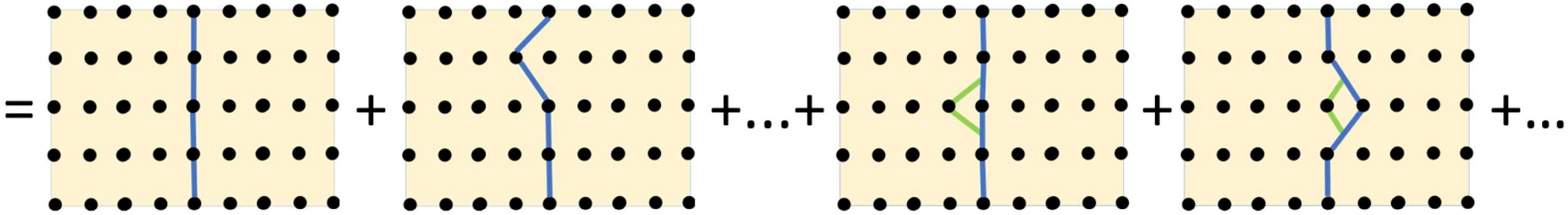
$$G(x,y) = i\int_0^\infty \langle x,l|y,0\rangle\, e^{-im^2 l} dl$$

$$\boxed{\langle x,l|y,0\rangle = \int d[x(l')]\,\exp\left\{i\int_0^l dl'\left[\tfrac{1}{4}g_{ab}\frac{dx^a}{dl'}\frac{dx^b}{dl'} - (\xi - \tfrac{1}{3})R(l')\right]\right\}}$$

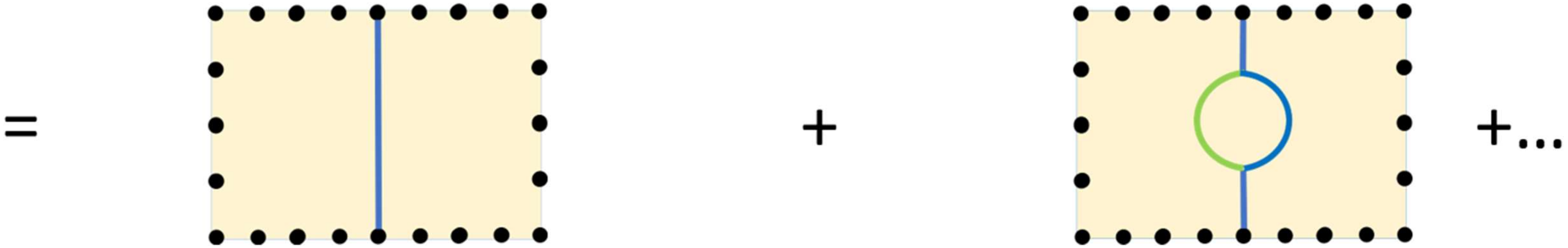
- Feynman, DeWitt, Parker, Bekenstein, Polyakov, Bern and Kosower, Strassler, Schmidt and Schubert……

QFT in terms of correlation diagrams





Correlation diagrams



Feynman diagrams

World Quantum Gravity: Idea

$$ds^2 = g_{ab} dx^a dx^b$$

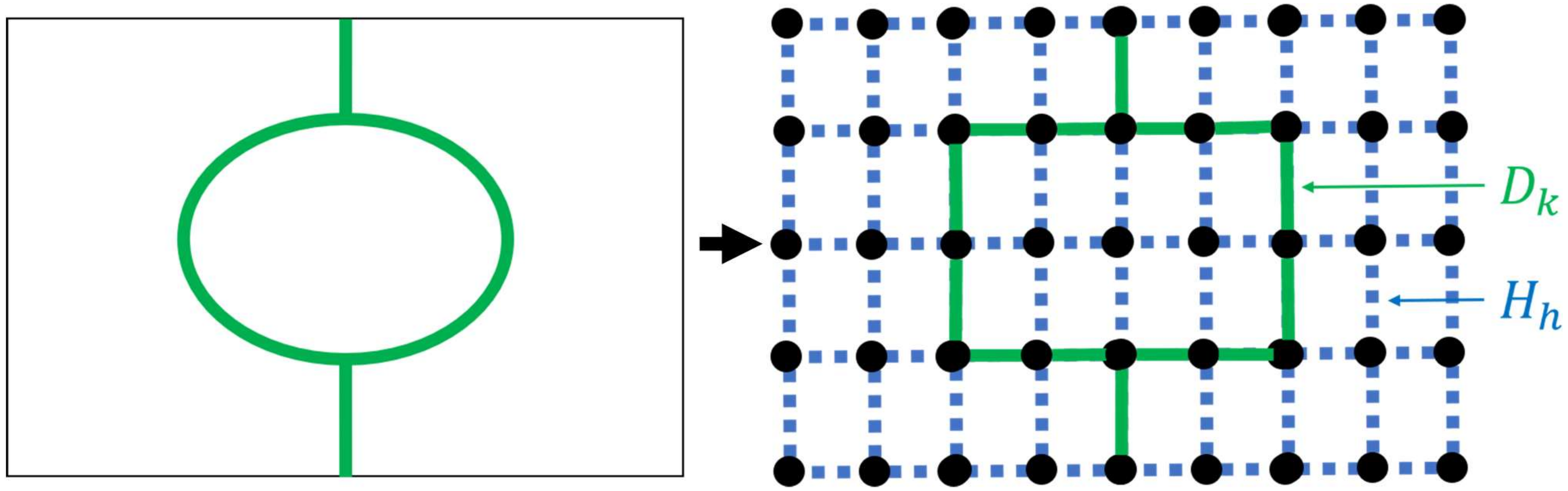
$$\boxed{\sigma(x,y) = \frac{1}{2}\int_x^y ds^2 \text{- Synge world function}}$$

$$g_{ab}(x) = -\lim_{y\to x} \frac{\partial}{\partial x^a}\frac{\partial}{\partial y^b}\sigma(x,y)$$

- arXiv: 1909.05322

World Quantum Gravity: Main formula

matter
QFT



WQG

Non-perturbative!

$$\sum_{\Gamma} \prod_i \int dx_i \frac{V[\Gamma]}{N[\Gamma]} \prod_{k\in\Gamma} G_k$$

$$\boxed{\lim_{\text{sk.}} \sum_{\Gamma} \sum_{g} \frac{V[\gamma_\Gamma]}{N[\gamma_\Gamma,\sigma]} \prod_{h\notin\gamma_\Gamma} H_h \prod_{k\in\gamma_\Gamma} D_k}$$

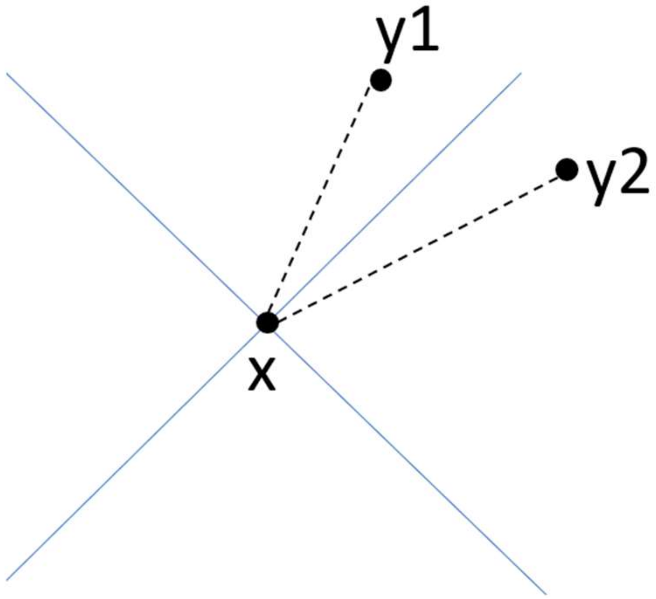
$$\boxed{H_h = \frac{\sigma_h}{\sigma_h - 6i\alpha_h s_h \Delta_h^{-1} \ln \Delta_h}}$$

$$\boxed{D_k = \Delta_k^{1-3\xi} \int_0^\infty \frac{dl_k}{(4\pi i l_k)^2} \exp\left\{ i[\sigma_k/2 - 3i\alpha_k s_k \Delta_k^{-1} \ln \Delta_k]/l_k - i m^2 l_k \right\}}$$

$$\alpha_j = \underset{\uparrow}{\zeta} \sum_{\{k,m,n\}} s_k s_m s_n / N \qquad s = |2\sigma|^{1/2} \qquad (\Box + m^2 + \xi R)\phi(x) = 0$$

Gravitational coupling

$$\Delta(s,\rho) = \operatorname{sinc}^{-3}\left(s\sqrt{\frac{\rho}{3}}\right) \qquad s\sqrt{\frac{\rho}{3}} < \pi$$



“Hardy sum”

Integration measure

$$\lim_{\text{sk.}} \sum_{\Gamma} \sum_{g} \frac{V[\gamma_\Gamma]}{N[\gamma_\Gamma,\sigma]} \prod_{h\notin\gamma_\Gamma} H_h \prod_{k\in\gamma_\Gamma} D_k,$$

$$\sum_{g} = \prod_{i} \sum_{g_i}, \quad \sum_{g_i} = \int_{-\infty}^{\infty} d\rho_i \int_{-a(\rho_i)^2/2}^{a(\rho_i)^2/2} d\sigma_i$$

$$\int_{-a^2/2}^{a^2/2} d\sigma f(\sigma) \tag{1}$$

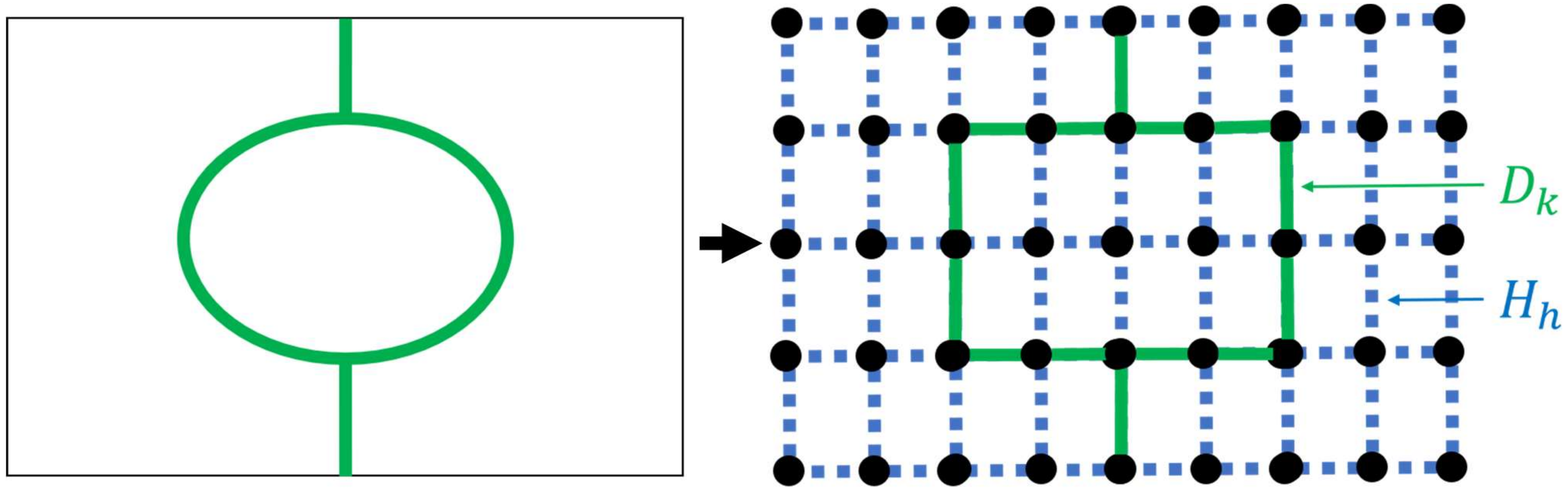
$$= \int_{-a^2/2}^{0} d\sigma f(\sigma=-s^2/2) + \int_{0}^{a^2/2} d\sigma f(\sigma=s^2/2) \tag{2}$$

$$= \int_{a}^{0} (-s ds)\ f(\sigma=-s^2/2) + \int_{0}^{a} (s ds)\ f(\sigma=s^2/2) \tag{3}$$

$$= \int_{0}^{a} ds\ s\ [f(\sigma=-s^2/2)+f(\sigma=s^2/2)]. \tag{4}$$

- Indefinite causal structure in action: Cancellation mechanism for divergences, real/imaginary parts, positive/negative parts etc.

UV divergence, singularity, predictions (evaluation)

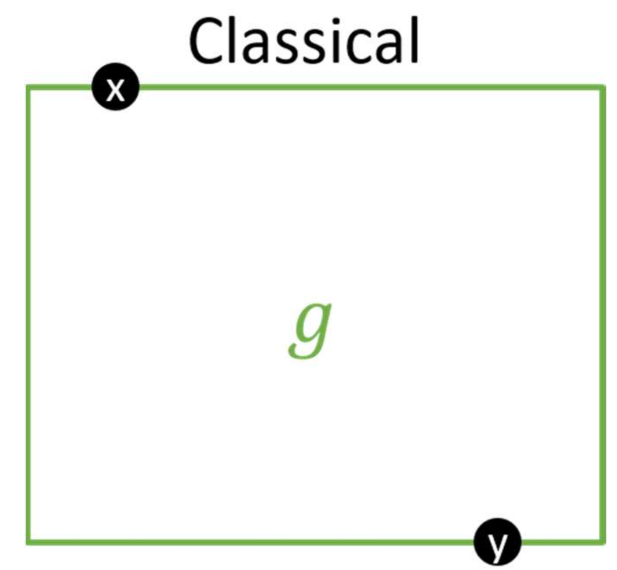


$$\boxed{\lim_{\text{sk.}} \sum_\Gamma \sum_g \frac{V[\gamma_\Gamma]}{N[\gamma_\Gamma,\sigma]} \prod_{h\notin\gamma_\Gamma} H_h \prod_{k\in\gamma_\Gamma} D_k}$$

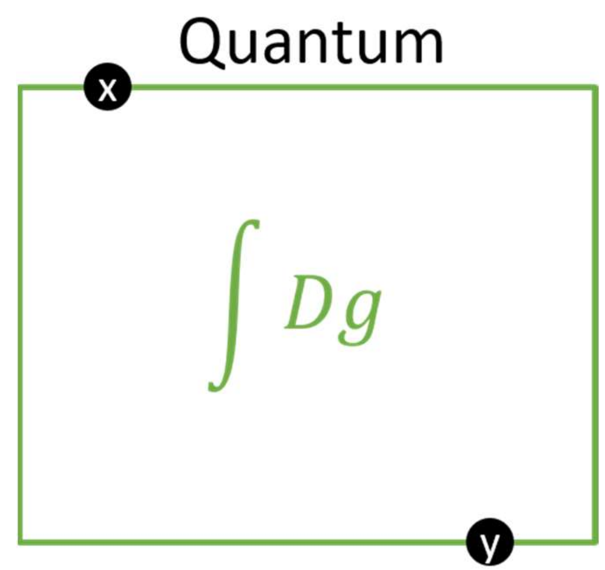
- Idea: Perform Hardy sum ■ over causal structures and study small distance limit
- Findings:
  1) Amplitude real and positive (up to convention) – efficient computation with Monte Carlo
  2) lim s->0, $■(H_h) \to 1$, $■(D_k)$ still has pole
  With QG integration measure factor s,
  $s_h ■(H_h) \to 0, s_k ■(D_k) \to 8i\alpha_k < \infty$, $\alpha_k = \zeta \sum_{\{k,m,n\}} s_k s_m s_n / N$
  3) Infinite curvature limit is $s_i \to 0\ \forall i$ => amplitude $\to 0$ – no singularity

Conjecture: UV divergences are killed by indefinite causal structure even in discrete theories?

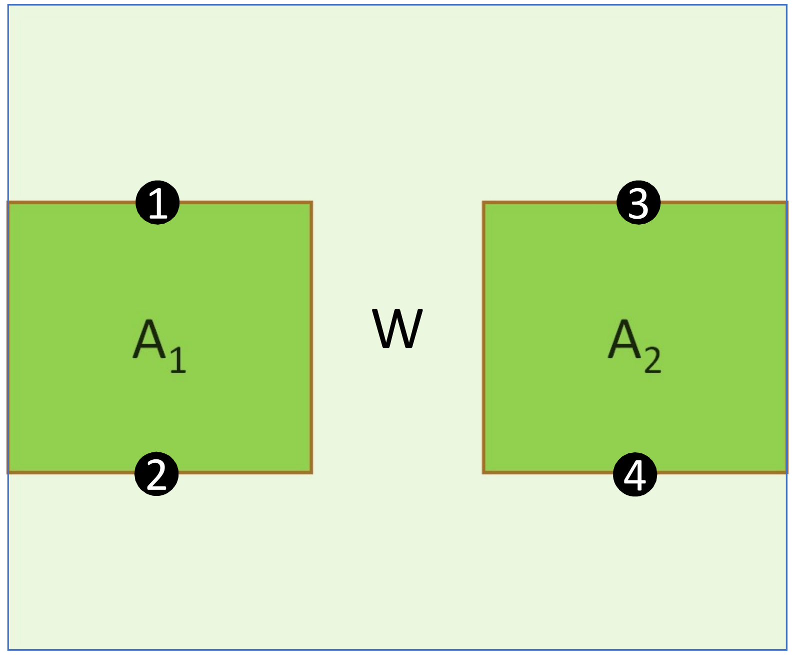
- ICS appears generically in theories admitting a path integral formulation



$x \rightarrow y$ or
$x \leftarrow y$ or
$x - y$



$$A_{x \rightarrow y} + A_{x \leftarrow y} + A_{x - y}$$



- Idea: Model-independent study of indefinite causal structure on correlations
- Finding: quantum correlation reduced continuously to zero with increasing causal structure quantum fluctuation (with qualifications)

- DJ, Quantum indefinite spacetime (Bachelor thesis), http://hdl.handle.net/10012/11998; DJ, Reduction of correlations by quantum indefinite causal structure, arXiv:1806.02331

Summary

arXiv: 1909.05322v2 (world quantum gravity)
arXiv:2001.03142 (correlational quantum theory)
And manuscript in preparation

- Correlation diagram formulation of quantum information
  -Application: characterization of processes with correlation constraint
- Correlation diagram formulation of quantum field theory
  -Feynman diagrams as topological classes of correlation configurations
- World Quantum Gravity
  -Non-perturbative, Lorentzian, path integral approach
  -Idea: relational variable $g_{ab}(x) \to \sigma(x,y)$
  -UV regular for both gravity and matter (seems)
  -Spacetime singularity-free (seems)
  -Efficiently computable: Real and positive (up to convention) amplitude after Hardy sum, suitable for Monte Carlo (seems)
  -Indefinite causal structure through Hardy sum crucial for all three features!

Valuable literatures

- Carlo Rovelli, Quantum Gravity
- Carlo Rovelli and Francesca Vidotto, Covariant Loop Quantum Gravity
- Claus Kiefer, Quantum Gravity
- Achim Kempf, Spacetime could be simultaneously continuous and discrete in the same way that information can
- Daniele Oriti, Approaches to Quantum Gravity
- Leonard Parker and David Toms, Quantum Field Theory in Curved Spacetime
- Laurent Freidel and David Louapre, Ponzano–Regge model revisited: I
- Rafael Sorkin, Forks in the Road, on the Way to Quantum Gravity
- Damiano Anselmi, Marco Piva, Quantum Gravity, Fakeons And Microcausality
- David Tong, Lectures on String Theory
- Eugenio Bianchi, Marios Christodoulou, Carlo Rovelli, and Hal Haggard, White Holes as Remnants
- Roberto Percacci, An Introduction to Covariant Quantum Gravity and Asymptotic Safety
- Renate Loll, A. Goerlich, Jan Ambjørn and Jerzy Jurkiewicz, Nonperturbative Quantum Gravity
- ……

Thanks for your attention!

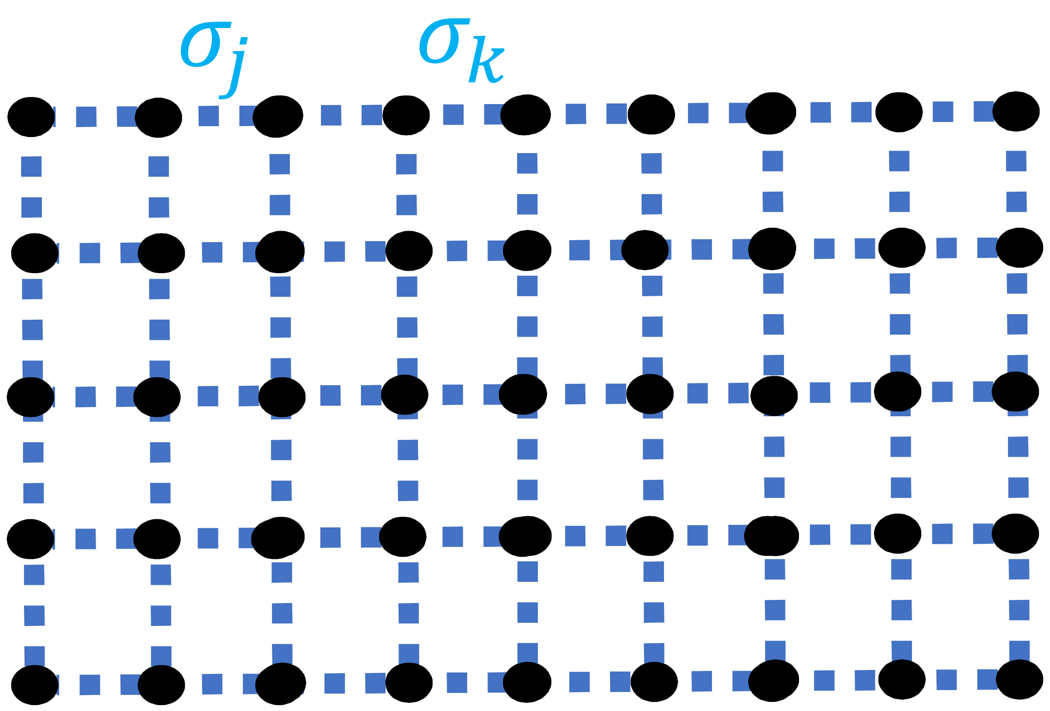
Marrying information and spacetime through correlation diagrams

arXiv: 1909.05322v2 (world quantum gravity)
arXiv:2001.03142 (correlational quantum theory)
And manuscript in preparation

Ding Jia (贾丁)
Perimeter Institute
University of Waterloo

QISS 2020
January 17, 2020
Hong Kong, China

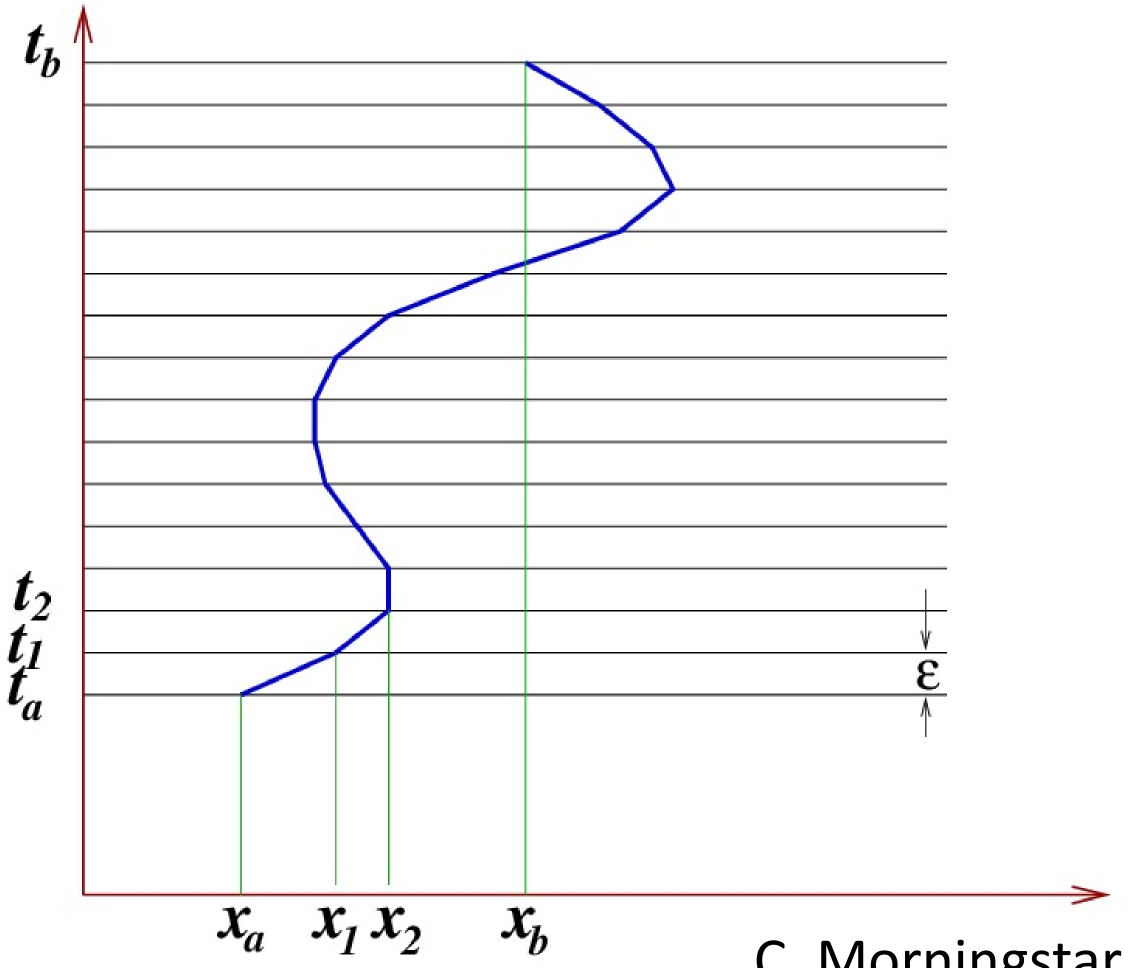
Locating σ on a skeleton



For concreteness, think of a 4D lattice graph

Fine-grain the graph to improve calculation

Algorithmic discreteness,
not necessarily fundamental!



C. Morningstar 2007

Think of the standard algorithm for
particle path integral

Integration measure

$$\lim_{\text{sk.}} \sum_{\Gamma} \sum_{g} \frac{V[\gamma_\Gamma]}{N[\gamma_\Gamma, \sigma]} \prod_{h \notin \gamma_\Gamma} H_h \prod_{k \in \gamma_\Gamma} D_k \tag{1}$$

$$\sum_{g} = \prod_{i} \sum_{g_i} \tag{2}$$

$$\sum_{g_i} = \int_{-\infty}^{\infty} d\rho_i \int_{-a(\rho_i)^2/2}^{a(\rho_i)^2/2} d\sigma_i, \tag{3}$$

$$a(\rho) = \begin{cases} \sqrt{\frac{3}{\rho}}, & \rho > 0, \\ \infty, & \rho \leq 0. \end{cases} \tag{4}$$

Define $A = s^2/2$, $B = 6\alpha_k s_k \Delta^{-1} \ln \Delta_k$. $A, B \geq 0$ [[Explain]]

$$\%H = \int_0^a ds\ s\left[\frac{-s^2/2}{-s^2/2 - 6i\alpha s\Delta^{-1}\ln\Delta} + \frac{s^2/2}{s^2/2 - 6i\alpha s\Delta^{-1}\ln\Delta}\right] \tag{9}$$

$$= \int_0^a ds\ s\left[\frac{-A}{-A - iB} + \frac{A}{A - iB}\right] \tag{10}$$

$$= \int_0^a ds\ s\left[\frac{A(A - iB + A + iB)}{(A + iB)(A - iB)}\right] \tag{11}$$

$$= \int_0^a ds\ s\left[\frac{2A^2}{A^2 + B^2}.\right] \tag{12}$$

For the gravity-matter correlator D, in the UV regime we can take the massless limit to simplify D into

$$D = \Delta^{1-3\xi}\int_0^\infty \frac{dl}{(4\pi i l)^2}\exp\{i[\sigma/2 - 3i\alpha s\Delta^{-1}\ln\Delta]/l\} \tag{13}$$

$$= \frac{1}{-8\pi^2}\frac{i\Delta^{1-3\xi}}{\sigma_k - 6i\alpha_k s_k\Delta^{-1}\ln\Delta_k} \tag{14}$$

$$(-8\pi^2)\%D = \int_0^a ds\ s[\frac{i\Delta^{1-3\xi}}{-A - iB} + \frac{i\Delta^{1-3\xi}}{A - iB}] \tag{15}$$

$$= \int_0^a ds\ s\ \frac{2B\Delta^{1-3\xi}}{-A^2 - B^2} \tag{16}$$